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Reuse of pulverized fired clay brick wastes as cement substitute in mortar for sustainable construction

Oluwarotimi Olofinnade[1,*], Anthony Ede[1], Julius Ndambuki[2], David Omole[1] Precious Francis[1], Cynthia Chigere[1] and Kehinde Oyeyemi[3]

[1]Department of Civil Engineering, Covenant University, Km 10, Idiroko Rd., Ota, Nigeria
[2]Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa
[3]Department of Physics, Covenant University, Km 10, Idiroko Rd., Ota, Nigeria
[*]Corresponding author: rotimi.olofinnade@covenantuniversity.edu.ng (OM Olofinnade)

Abstract. Recently, there has been an increase on the use of waste materials for development of new materials for construction. This is due to the need for sustainable development which emphasizes on waste reduction, reduction of greenhouse gases (GHG), greener clean environment and conservation of raw resources. This study examines the appropriateness of clay brick waste in powder form as a suitable material for partial substitute of cement in mortar. The clay bricks were obtained as generated waste materials from a brick producing factory in Lagos metropolis and then subjected to grinding. Tests which include; specific gravity, particle size distribution, x-ray fluorescence and scanning electron microscopy were carried out on the pulverized clay brick material (CBP). Further, it is used to partially replace cement in mortar at replacement percentage of 0, 5, 10, 20, 25, 30, 40 and 50% using a mix ratio of 1: 2.75 at 0.45 water-cement ratio. Compressive strength and strength activity index tests were carried out on the cube specimens after days of curing. The obtained results clearly indicate that the pulverized clay brick is an amorphous material and contains similar chemical oxide compounds of a pozzolana. Furthermore, it was observed that the compressive strength of the mortar was further improve at an optimum value of 20% cement replacement with clay brick powder compared to the control mortar. Therefore it implies that generated clay brick wastes can be pulverized and used as pozzolanic admixture in mortar production instead of discriminate dumping in landfill.

1. Introduction

In recent years, increasing concerns on the needs to protect the environment necessitate the creation of the concept of sustainable construction in the construction industry. According to [1], the practice of sustainable construction implies responsible management of the built environment considering efficiency of material resources and ecology. Moreso, the origin of sustainable construction can be traced to the concept of sustainable development which emphasized on the needs for the present generation to meet their own needs without compromising the ability of future generations to meet theirs [2]. In addition, the amount of generated wastes and by-products from households and industries are increasing at an alarming rate due to increase population and urbanization. Although wastes generation are unavoidable aspects of human action, however, it is important that urgent steps be taking to reduce the amount of generated wastes and also finding a viable alternatives of recycling and reusing produced wastes. Furthermore, it was emphasized by [3] that recycling and reusing of waste is very necessary from the view point of protecting and preserving the environment. In addition, study by [4] stated that the 3R (reduce, reuse and recycle) initiatives is now a globally recognized tool that can

contribute to the reduction of greenhouse gases (GHG) emission. The construction industry, is a major consumer of natural resources and also producing large amount of wastes. A study by Cachim [5] indicated that about half of the wastes generated by the developed nations have their sourced in construction and demolition wastes (C&DW). The C&D wastes mainly consist of materials such as; wood, concrete, clay brick, mortar, glass, plastic, aluminium and steel that are commonly used in civil construction. However, at same time, there is also an increasing concern with the consumption rate of the natural resources in the construction industry and the impact on the environment. Concrete is one of the main construction material in the construction industry and will remain so in the future [6, 7]. According to Naik [8], concrete is versatile and economical, and has today become a major construction material, however, it has impacts on the environment [8]. For instance, cement, is one of the vital component material of concrete and mortar, however, its production process generates a great deal of dust and carbon dioxide (CO_2) [9, 10]. A study by [6] and [11] pointed out that in year 2000, about 1.25 billion tons of CO_2 was released to the atmosphere only from production of cement resulting in serious environmental pollution. This implies that finding a way of limiting the portion of cement in mortar or concrete can extenuate environmental pollution. In addition, [5, 20] emphasized that the impacts of using concrete and mortar on the environment can be minimize by reusing some of the generated wastes as alternative materials to partially replace cement in the concrete or mortar to ensure resource preservation and reduction of GHG emissions.
There are some C&D wastes such as clay brick that possess the required chemical compositions for a binder substitute. In addition, several studies have reported that using mineral admixture such as; fly ash and slag which are sourced as wastes to partially substitute cement in concrete is a good way to turn waste into wealth, as well as achieving a sustainable environment. Moreover, because of the composite nature of concrete, it provide a real means of managing wastes in good quantities [3, 12]. Clay brick materials are largely used in Nigeria, for building construction [9]. Consequently, large amount of wastes are generated by the brick factories and the construction industry (as demolition wastes) and often time these wastes are dumped in landfills. However, previous research studies have reported on the possibility of reusing crushed clay brick wastes as coarse aggregate, fine aggregate and mineral admixture in concrete [9], [13-18]. Moreover, studies by [9], [15], [18], [19] mentioned that clay brick wastes are potential pozzolana, which can be utilize as cement substitute to help reduces the impact of cement on the environment. Besides, studies by [24] stated that about 30-50% of the generated 5 billion tons of construction waste all over the world are made up of clay brick wastes. Moreover, in Nigeria, the ceramic and clay brick industries produced large amount of brick and ceramic products annually, and therefore generated huge amount of brick wastes which are mostly disposed in landfills, or dumping sites posing as environmental challenge [9], [18]. Studies by [15, 18] reported that comminuted fired clay brick wastes possess pozzolanic cementitious properties, and a more valuable alternative resources for construction instead of discriminate dumping in landfill. Therefore, this present study is aim to characterize and investigate the effect of using pulverized locally sourced clay brick wastes as partial substitute for cement on the properties of mortar for sustainable construction.

2. Methodology

The cement used in this study for the mortar production is the ordinary Type I Portland cement (OPC) of grade 42.5 conforming to the specification requirements of [21]. The clay brick materials was obtained locally as generated wastes from a brick producing factory located within Lagos metropolis, Nigeria. The clay brick materials were crushed and ground to the required fineness, and then sieved through a BS mesh of 75 micron opening so as to achieve a uniform particle sizes. Physical, chemical and microstructural characterisation were conducted on the cement and clay brick powder (CBP) samples. The sand used in the mortar mixes was sourced commercially. For the production of the reference mortar, sand (passing through 4.75 mm sieve but retained on 0.075 mm sieve) combined with ordinary Portland cement were used for the mixes. The particle size distributions and fineness modulus of the sand was determined by sieve analysis. The mix proportion of the mortar mixes was selected in compliance to ASTM C109 [22], using mix ratio of 0.45:1:2.57 (water: cement: sand) by mass for each test property. For each mix, the cement content consisted of OPC and blended mix of

OPC and CBP. The portion of the clay brick powder was used to partially replaced cement by the proportions: 0, 5, 10, 20, 25, 30, 40 and 50% (Table 1). The binders was thoroughly mixed together in order to ensure even blending and distribution of all constituents. Mortar cubes of dimension 100 x 100 x 100 mm were casted in mould, covered with plastic sheets and removed after 24 hours. Each specimen was appropriately labelled for identification and cured in water by immersion until the age of test. The cubes specimens were tested for compressive strength at ages of 3, 7 and 28 days for each percentage replacement of cement with CBP in the mortar [22]. The average strength of three specimens was determined for the various tests. The compressive strength was carried out using YES-2000 digital display compression machine.

Table 1. Batching of mortar mixes

Materials	0%	5%	10%	20%	25%	30%	40%	50%
Sand (kg)	11	11	11	11	11	11	11	11
Water (kg)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Cement (kg)	4	3.8	3.6	3.2	3.0	2.8	2.4	2.0
CBP (kg)	-	0.2	0.4	0.8	1.0	1.2	1.6	2.0

Table 2. Physical properties of mortar constituents

Properties	OPC	CBP	Sand
Fineness Modulus			2.69
Specific gravity	3.15	2.52	2.62
Water absorption		0.15	0.42

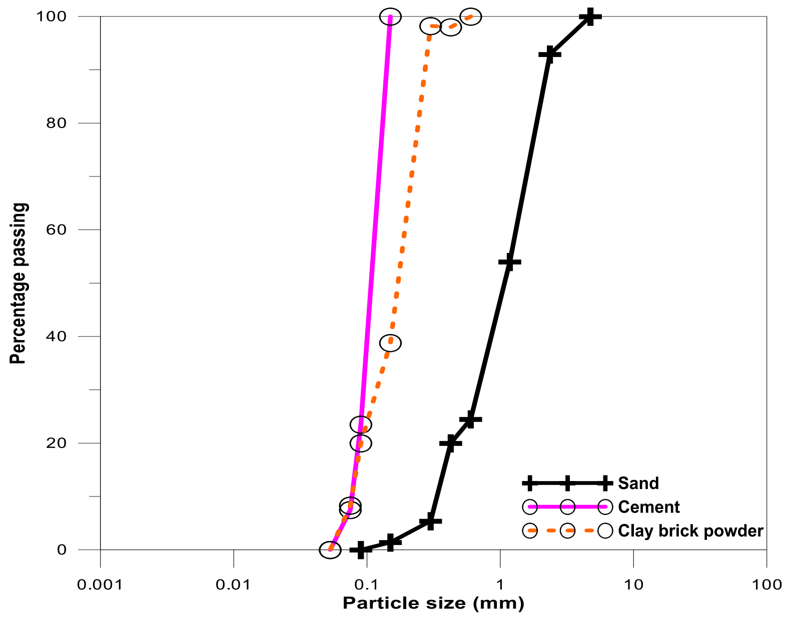


Figure 1. Particle size distribution for sand, cement and CBP

3. Results and Discussion

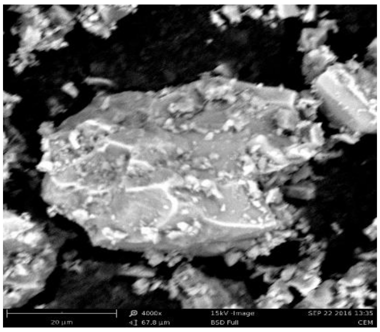
Figure 1 shows the particle size distribution of the sand, CBP and cement used in this study. The figure clearly indicate that the sand can be classified as a uniformly graded sand (SP). An indication that the sand material is good for producing mortar. Meanwhile, the particle size distribution for the

CBP was noticed to be slightly similar to that of cement, implying the promising property of the CBP to be blend with a binder material as mineral addictive. The physical properties of the CBP, cement and sand are presented in Table 2. Meanwhile the results of metallic oxides composition tests using the X-ray fluorescence (XRF) conducted on the cement and clay brick powder are depict in Table 3. The result clearly depicts the high silica and alumina content (60.64% and 14.23%) in the CBP material as required for a natural pozzolanic material. In addition, based on the recommendation of ASTM C618 [23], CBP can be classify as class N pozzolan since the addition of the percentage compositions of Fe_2O_3, SiO_2 and Al_2O_3 (79%) is above the minimum requirement of 70% for a class N pozzolan. The loss on ignition (LOI) value is less than 10%, while the SO_3 is less than 4%. It is expected that class N pozzolan will show more pozzolanic tendency compare to any other pozzolans.

Table 3. Chemical composition for cement and CBP materials

Compositions	Cement (%)	Clay brick powder (CBP) %
SiO_2	24.08	60.64
Al_2O_3	19.40	14.23
Fe_2O_3	6.28	4.93
CaO	74.25	0.27
MgO	3.96	1.72
K_2O	0.85	1.44
Na_2O	1.74	1.94
TiO_2	0.62	0.98
P_2O_5	1.21	0.90

Furthermore, the results of the scanning electron microscope (SEM) carried out on the CBP and cement materials are presented in Figure 2.


(a)

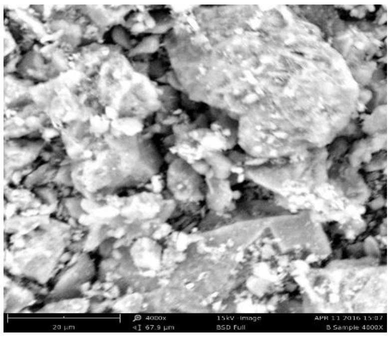

(b)

Figure 2. Particle morphology (a) Cement; (b) Clay brick powder (CBP)

The SEM micrograph clearly reveal the morphology of the CBP particles as rounded grains with rough geometry compare to the broad and round solid shapes of the cement particles. The SEM shows the existence of amorphous solid mass structures of the CBP materials. Moreover, the energy dispersive x-ray spectrometer (EDX) results also reveal silicon, aluminium, and oxygen as dominant elements in the CBP. This shows the suitability of CBP material to be adopted as pozzolanic addition in mortar for sustainable construction. The strength activity index (SAI) determined in accordance with ASTM C311 [25] on mortar specimens for 7 and 28 days clearly depicts that fired clay brick powder satisfied the requirements to be used as pozzolana in concrete or cement mortar for partial substitute for Portland cement.

3.1. Strength

The strength development of the mortar containing CBP is vital because it gives an indication to the quality of the mortar mix and subsequent usage as construction material. The results of the compressive strength for reference mortar and mortar containing different percentage dosages of CBP are shown in Figure 3. The obtained results indicate an increase in the compressive strength of the mortar at various mixes as the age of curing increases. However, it was observed that an increase in CBP content in the mortar mixes resulted in the reduction of the compressive strength from above 20% CBP. Further, a gradual increase in the strength was noticed at lower CBP addition of 5 and 10%. Meanwhile, the addition CBP at 20% replacement resulted in higher strength at 28 days curing compare to the other mixes. The dosage level of 20% is considered the optimum level for partial cement replacement with CBP.

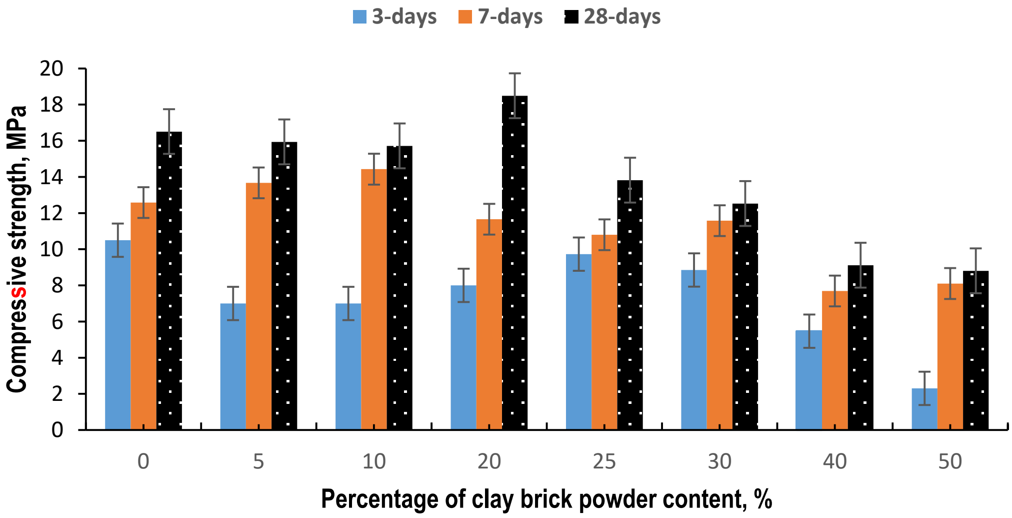


Figure 3. Strength development of control and mortar specimens containing CBP

4. Conclusion

This study examines the sustainable reuse of clay brick wastes pulverized into powder as substitute for cement in mortar production. The following conclusions can be drawn from this study:

i. The chemical compositions of clay brick powder suggest that the material can be classify as class N pozzolan material following the suggestions of ASTM C618 report on pozzolanic materials.

ii. The strength of mortar was significantly improve with the incorporation of clay brick powder (CBP) up to 20%. However, the highest strength was achieved at 20% CBP content after 28 days of curing, implying that the possible optimum CBP content in mortar can be up to 20%. This study clearly indicate that clay brick powder can be adopted as mortar component for innovative construction material in sustainable building construction.

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